AIR DENSITY CORRECTIONS FOR X-RAY IONIZATION CHAMBERS

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ABSTRACT

The international Röntgen is defined only for a given density of air (as affected by temperature and pressure). Since ionization measurements are usually carried out at other than the standard density, corrections must be made therefor. These corrections are discussed and their applications are given for (*a*) standard ionization chamber measurements, (*b*) calibration of thimble chambers against a standard, (*c*) clinical use of thimble chambers at other than the prescribed air density, (*d*) radioactive leaks for ionometer sensitivity control, and (*e*) radioactive compensators for ion current measurement.

CONTENTS

I. INTRODUCTION

The unit of X-ray quantity, the Röntgen,[1, 2] has been defined by international agreement in terms of the ionization produced under stated conditions in a cubic centimeter of atmospheric air. The ionization which a given X-ray beam will produce in a given volume of air is simply proportional to the number of molecules of the air exposed to the rays; that is, proportional to the density of the air.

The density of atmospheric air depends upon the following factors: (1) Composition, (2) moisture content, (3) temperature, and (4) pressure. Air composition is extremely uniform for altitudes up to 15 km. and over the earth's surface. Ordinary variations in density resulting from change in composition do not affect the ionization produced in air. A change in temperature of 10° C. causes a change in air density due to its moisture content of only about one-half per cent. It is therefore assumed that air density changes are due entirely to variations in temperature and pressure. The density of unconfined air varies inversely as its absolute temperature and directly as its pressure. The röntgen is therefore uniquely defined when these conditions are given. To fulfill this requirement the definition states that the ionization shall be measured in air at a temperature of 0° C. and a pressure of 760 mm mercury.

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[1] The quantity of radiation which, when the secondary electrons are fully utilized and the wall effect of the chamber is avoided, produces in 1 cubic centimeter of atmospheric air at 0° C. and 76 cm mercury pressure such a degree of conductivity that one electrostatic unit of charge is measured at saturation.

[2] Third International Congress of Radiology, Paris, 1931.

In formulating this definition it was not, of course, intended that ionometers should necessarily be calibrated nor that dosage measurements should necessarily be made at 0° C. and 760 mm pressure, for while not impossible, it would be extremely impractical. It was recognized that, regardless of what temperature and pressure were specified as standard, calibration and dosage measurements would be made in general under different conditions; and that this would involve temperature and pressure corrections.

Because they were of about the same order of magnitude as the error involved in the measurements, until recently, little attention has been given these corrections. Now that it is possible to make the measurements more accurately (within 0.25 per cent), these corrections can no longer be neglected. In the calibration of an ionometer there are three separate temperature and pressure corrections involved. The first is applied to the standard chamber, the second and third to the ionometer reading. These will be discussed in turn and a simplification of the process, arising from the simultaneous application of the first and second correction factors, will be noted.

II. TEMPERATURE AND PRESSURE CORRECTIONS APPLIED TO STANDARD IONIZATION CHAMBER

By the definition of the Röntgen, ionization due to "wall effects" is excluded. It is therefore to be expected that, in the open-air ionization chamber where this condition is most nearly realized, the ionization produced would vary directly as the density of the air. The density d_o at 0° C. (273°, absolute) and 760 mm mercury may be calculated from the density d_t at temperature t° C. ($273+t$, absolute) and pressure p by the equation[3]

$$d_o = d_t\left(\frac{273+t}{273}\times\frac{760}{p}\right) \tag{1}$$

Since then the ionization in the open-air chamber varies directly as the air density, number of Röntgens, r, should be given by

$$\begin{aligned} r &= I_o \\ &= I_t\left(\frac{273+t}{273}\times\frac{760}{p}\right) \\ &= I_t k \end{aligned} \tag{2}$$

Where I_t is the observed ionization per milliliter in e. s. u. at t° C. and p mm mercury and I_o is the corresponding ionization per milliliter in e. s. u. at 0° C. and 760 mm mercury.[4]

This relationship was tested experimentally first by McClung [5] in 1904 and by Crowther [6] in 1909, and found to hold within the experimental accuracy. The factor k is the air density correction which must be applied to the ionization, I_t, measured under any fixed con-

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[3] This equation is an approximation good to about 0.1 per cent. The more exact expression is

$$d_o = d_t\,(1+0.00367\,t)\,\frac{760}{p}$$

[4] To distinguish between I_t and I_o in (2), Victoreen (Radiology, November, 1931, p. 1014), refers to I_o as "Röntgens reduced to zero."

[5] R. K. McClung, Phys. Zeit., vol. 5, p. 368, 1904; also, Phil. Mag., vol. 7, p. 81, 1904.

[6] J. A. Crowther, P. R. S., 1909.

ditions of temperature and pressure, in order to determine the value called for by the definition of the Röntgen. Values of k for the range of temperatures and pressures ordinarily encountered are plotted in Figure 1. This factor, therefore, enables us to determine the X-ray quantity in Röntgens under any condition, for we have simply to measure the ionization per milliliter and then multiply by k to get the ionization in e. s. u. at 0° C. and 760 mm mercury pressure. This by definition gives the X-ray quantity in Röntgens.

In the preceding discussion of the temperature-pressure correction, as applied to the standard ionization chamber, it is tacitly assumed that the electrostatic measuring system is independent of temperature and pressure. This assumption holds for all deflection systems, and for null systems involving either electrostatic compensators or hermetically sealed radioactive compensators. It does not hold for systems which are not hermetically sealed.

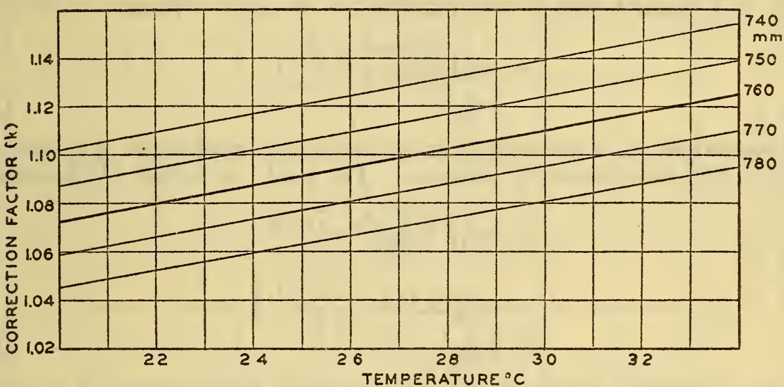

Figure 1.—*Correction factor to reduce ionization in e. s. u. per milliliter at a given temperature and pressure to Röntgens (e. s. u. per milliliter at 0° C. and 760 mm mercury)*

In any radioactive compensator the current is produced by air ionization which varies according to the same laws as X-ray ionization and hence is likewise subject to corrections for air density unless hermetically sealed. In the unsealed compensator the density variation is identical with that in the air ionization chamber, so that when the two are used simultaneously the air density correction experimentally vanishes. In such a case, however, it is of importance to know the air density for which the compensator calibration was made in order that the readings may be reduced by (2) to the standard density.

III. TEMPERATURE AND PRESSURE CORRECTIONS AS APPLIED TO IONOMETERS

Whether the simple air density corrections which apply for the open-air ionization chamber are also applicable to ionization chambers which are not free from "wall effects" is not known with a high degree of certainty. However, pending experimental proof, it has been universally assumed that the same corrections apply to chambers of the thimble type or others having appreciable "wall effects." The necessity for applying an air density correction when calibrating an ionometer arises from the fact that ionometers are often used at temperatures and pressures other than those at which the calibration is made. If an ionometer receiving a given number of Röntgens (r) at known temperature (t_c) and pressure (p_c) gives a scale deflection of θ_c, it would on receiving the same number of Röntgens at some other temperature (t_w) and pressure (p_w) give another deflection (θ_w)

$$\theta_w = \theta_c\left(\frac{273+t_c}{273+t_w}\times\frac{p_w}{p_c}\right) \tag{3}$$

This correction is applied at the time of calibration of the ionometer against the standard.

Since, in general, the air density in the clinic will be variable, a second correction to be applied by the radiologist may be necessary. This is required if, at the time the ionometer is used, the temperature (t_a) and pressure (p_a) differ from the temperature (t_w) and pressure (p_w) under which it was *intended* to be used. Thus

$$\begin{aligned}\theta_w &= \theta_a\left(\frac{273+t_a}{273+t_w}\times\frac{p_w}{p_a}\right)\\ &= \theta_a c'\end{aligned} \tag{4}$$

Ionometers of American manufacture are calibrated for use at 22° C., 760 mm mercury pressure. For such, equation (4) becomes

$$\begin{aligned}\theta_w &= \theta_a\left(\frac{273+t_a}{295}\times\frac{760}{p_a}\right)\\ &= \theta_a\left(2.576\times\frac{273+t_a}{p_a}\right)\\ &= \theta_a c\end{aligned} \tag{5}$$

The correction factor in (5) (quantity in parentheses) is usually obtainable, for the range of temperature and pressure conditions ordinarily encountered, from a chart supplied by the manufacturer. It may likewise be obtained from Figure 2. Ionometers graduated to read Röntgens directly, can be correct only at the temperature and pressure at which it is intended that they be used. Under other conditions corrections must be made either by equation (4), (5), or from the chart supplied by the manufacturer.

It should be emphasized that the radiologist need make only one of the corrections discussed above and then only when high accuracy is desired. For small variations in temperature (±3° C.) about the calibrated operating temperature (22° C.), the error introduced by neglecting the air density corrections will be only ±1 per cent. Similarly a variation in atmospheric pressure of ±10 mm Hg will introduce an error of about ±1 per cent. The sum of these errors will usually lie within the experimental error of an ionometer as used clinically.

IV. APPLICATION OF AIR DENSITY CORRECTIONS TO CALIBRATION OF AN IONOMETER

Let it be required to calibrate an ionometer to measure Röntgens correctly at a temperature t_w and pressure p_w. The temperature at the time of calibration is t_c and the pressure p_c. The ionization current produced by a constant X-ray beam is first measured by

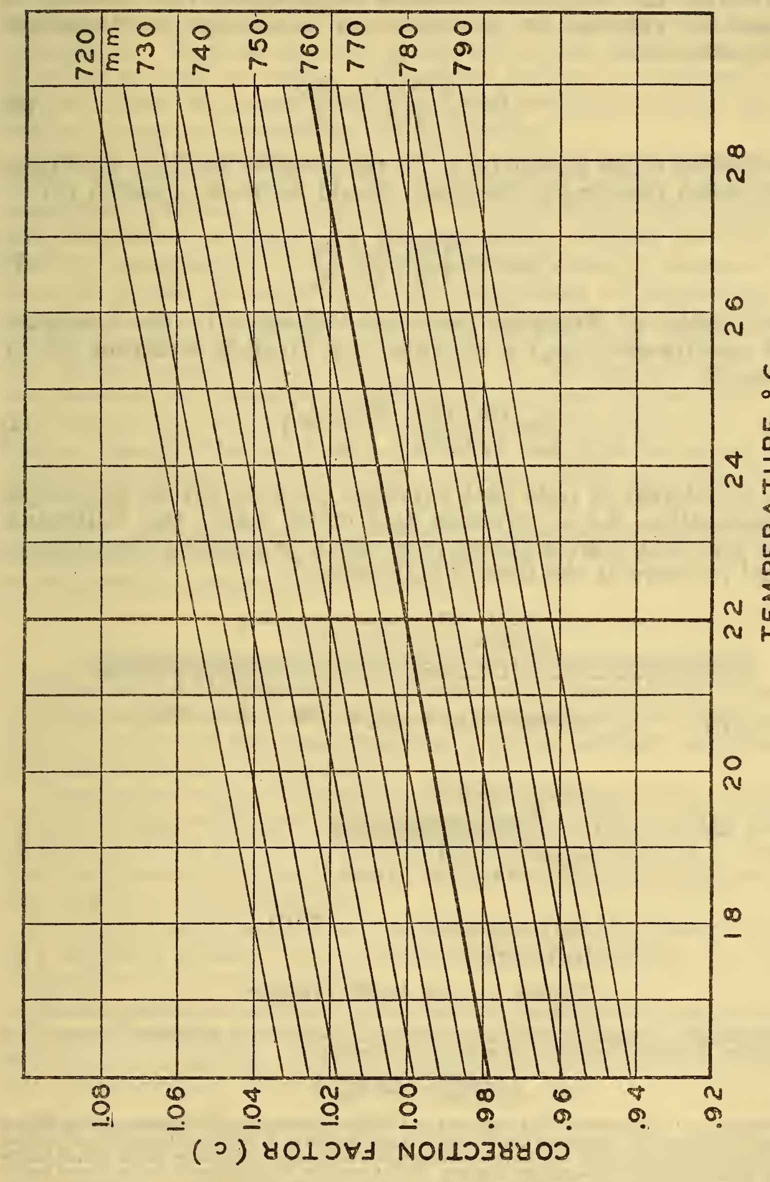

FIGURE 2.—*Correction factor (c) to be applied to an ionometer intended for use at 22° C., 760 mm mercury when used under other conditions*

means of a standard ionization chamber which indicates I e. s. u. per milliliter of air per minute. The ionometer is then placed in this beam and after m minutes shows a deflection of θ_c.

Correcting the standard chamber magnitude, the number of Röntgens (r) entering the ionometer in m minutes is determined from equation (2)

$$r = Im \times \frac{273 + t_c}{273} \times \frac{760}{p_c} \tag{6}$$

The deflection of the ionometer θ_w for the specified working conditions (t_w, p_w), when receiving r Röntgens, should be, from equation (3)

$$\theta_w = \theta_c \frac{273 + t_c}{273 + t_w} \times \frac{p_w}{p_c} \tag{7}$$

The number of Röntgens per scale deflection of the ionometer (under conditions t_w, p_w) is obtained by dividing equation (6) by equation (7)

$$\frac{r}{\theta_w} = \frac{Im}{\theta_c} \left(\frac{760}{273} \times \frac{273 + t_w}{p_w} \right)^{7} \tag{8}$$

It is of interest to note that equation (8) does not involve either the temperature (t_c) or pressure (p_c) under which the calibration is made and that there is therefore no need for knowing the temperature and pressure at the time of calibration.[8]

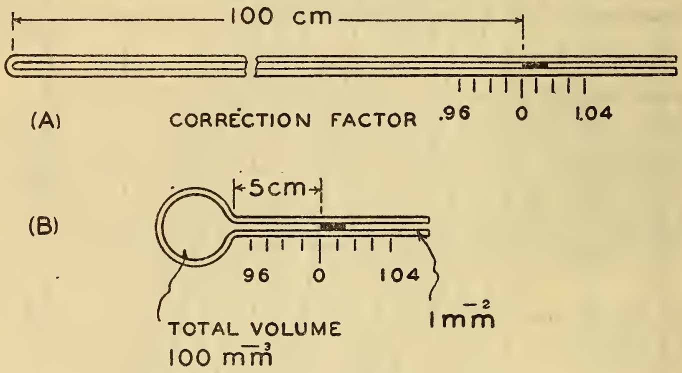

FIGURE 3.—*Air density indicator*

[7] For all ionometers of American manufacture and for those calibrated at the Bureau of Standards t_w is 22° C. and p_w is 760 mm of mercury. Equation (8) then becomes

$$\frac{r}{\theta_w} = \frac{Im}{\theta_c} \frac{295}{273} = (1.081) \left(\frac{Im}{\theta_c} \right)$$

[8] W. Nicholas, of this laboratory, has suggested and used a simple means of obtaining the air density correction without actually measuring the te⁻⁻perature and pressure. A globule of mercruy in a capillary tube sealed at one end (fig. 3 (*a*)) will move according to the air density in the tube, which will, of course, vary with temperature and atmospheric pressure. If, for example, the tube has a uniform cross section and the globule is 100 cm from the sealed end, each centimeter of motion of the globule will represent about 1 per cent change in air density, giving directly the correction necessary to apply to the ionization readings. A modification of this suggestion would be to replace the long tube by a capillary and bulb of known volumes (fig. 3 (*b*)) so as to reduce the size of the apparatus. Such a device may be mounted directly on an ionometer for convenience.

V. TEMPERATURE-PRESSURE CORRECTIONS APPLIED TO RADIOACTIVE IONOMETER CONTROLS

Since ionometers are for the most part delicate instruments it is essential that some means be provided for occasionally checking their calibration. Radium or some other radioactive substance is usually provided as such a control. Since the ionization produced by the control follows the same law as for X-ray ionization similar temperature and pressure corrections are applicable.

It is therefore recommended that air density corrections on radioactive controls be made in the same manner as the corresponding corrections applied to ionometers. At the initial calibration, the scale deflection produced by the radioactive control per unit time (ratio of deflection to time) should be found, and by means of equation (3) should be corrected to the conditions of temperature and pressure (t_w, p_w) for which it is intended that the ionometer be used. When at any time the ionometer is to be checked by this control the deflection-time ratio must again be determined for existing temperature and pressure conditions (t_a, p_a) and this ratio by means of equation (4) reduced to the working conditions (t_w, p_w). By this means a check obtained from a control of this type has a real significance; a good agreement between the initial check and that obtained later (both for conditions t_w, p_w) indicating that the calibration of the ionometer has remained unchanged. Capacity controls have recently been incorporated in certain ionometers which do not require corrections for temperature or pressure.

VI. CONCLUSIONS

Of the temperature-pressure corrections discussed, that to be applied to the standard ionization chamber correcting from room temperature to 0° C., is by far the most important; under ordinary conditions it amounts to about +8 per cent.

In order to measure dosage accurately by means of an ionometer which has been calibrated in Röntgens, the following factors must be known: (1) The temperature and pressure for which it is intended that the ionometer be used, (2) the actual temperature and pressure at the time the ionometer is used.

In order to effect an accurate calibration of an ionometer by means of a standard chamber the temperature and pressure at the time of calibration need not be known.

The temperature-pressure correction to be applied to an ionometer will vary from about −2.0 per cent to +4.0 per cent. For extremes in temperature and for the low atmospheric pressures at high altitudes this correction may be as large as +7.0 per cent.

WASHINGTON, January 8, 1932.